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ABSTRACT

The activities during the first half of 1995 supported with MODIS funding have been concentrated on a combination of field sampling and theoretical optical modelling to refine our version 1 ATBDs (Algorithm Theoretical Basis Document) consisting of algorithms for chlorophyll a, Instantaneous Photosynthetically Available Radiance (IPAR), and clear-water epsilons. The IPAR provides both spectral downwelling irradiance at the sea surface and spectral photon flux into the sea surface to convert Abbott's chlorophyll fluorescence measurements into fluorescence efficiencies. The algorithms and optical data and data products derived from cruises in 1993-4 on the West Florida Shelf have been submitted to the MODIS Ocean Science team computing facility. Three bio-optics experiments were conducted, two in the Florida Keys, and one in the Arabian Sea. Three peer-reviewed papers have been accepted for publication, two presentations made, and three papers have been submitted for publication.

TASKS ACCOMPLISHED

Field Work

An optical experiment was conducted in the lower Florida Keys on the RN Bellows between March 12 and 17, 1995. The emphasis of the cruise was hyperspectral measurements of the bottom albedo and the effects of bottom reflected radiance on various algorithms. Samples collected included the following: remote sensing reflectance, in situ albedo measurements made by divers and in vitro measurements of cores for carbonate sand, grassy bottom, and coral; the absorption coefficients of partitioned water samples, and conductivity -temperature-depth (CTD) and chlorophyll fluorescence profiles.

An optically-instrumented ROV was tested on an RN Suncoaster cruise from Tampa Bay to Key West along the Florida west coast between April 2 and 6, 1995. Samples taken included bottom albedo measurements around Looe Key National Sanctuary, the absorption coefficients of water samples, CTD/chlorophyll/gelbstoff fluorescence profiles, and remote sensing reflectance data. Pigment and in-water optical measurements were made by cruise collaborators.

Remote sensing reflectance and absorption coefficients of partition water samples were collected on a ocean biological processes cruise in the Arabian Sea aboard the R/V Thompson. The cruise was conducted during monsoon conditions and transited area of high and low productivity. In addition to the ship activities, our group provided instrumentation and personnel to intercalibrate with the aircraft instruments. The Airborne Oceanographic Lidar was flown on the P3 aircraft over the ship tracks.

DATA / ANALYSIS/ INTERPRETATION

A paper by Carder et al. (1995) that calculates the quantum yield of photosynthesis has been published. The quantum yield o of photosynthesis (mol C (mol photons) $^{-1}$) at 6 depths for the waters of the Marine Light-Mixed Layer (ML-ML) cruise of May 1991 were calculated. As there were *PAR* (photosynthetically available radiation) but no spectral irradiance measurements available at four depths for each of the primary production incubations, three ways were presented for the calculation of the absorbed radiation by phytoplankton for the purpose of calculating o. The first was based on a simple, nonspectral model; the second was based on a nonlinear regression using measured *PAR* values with depth; and the third was derived using hyperspectral remote sensing measurements. We show that the results of o calculated using the nonlinear regression method and those using remote sensing are in good agreement with each other, and are consistent with the reported values of other studies. In deep waters, however, the simple nonspectral model performed worse, as expected, and even resulted in some estimated quantum yield values that were much higher than theoretically possible.

A method to derive the spectral absorption coefficients of the ocean using a remote-sensing reflectance model by Lee et al. (1995) has been submitted to Applied Optics. Using data from diverse environments such as the Gulf of Mexico and Monterey Bay, total absorption coefficients derived by the method and from in-water measurements are compared. These results at 440 nm and 488 nm have r^2 correlation coefficients of 0.95 and 0.97, respectively, indicating that the method works very well in retrieving in-water absorption coefficients from remotely measured signals alone, and may be of wide potential use in the remote sensing applications such as estimating primary production and fluorescence efficiency.

A paper regarding the adjacency effect by Reinersman et al. (1995) has been accepted for publication in Applied Optics. A simple “backward” Monte Carlo technique was used to investigate the effect on the atmospheric point spread function (PSF) of aerosol phase function, sensor viewing angle, aerosol optical thickness, and wavelength. The simulations assumed a Lambertian surface reflectance and a stratified, horizontally homogeneous atmosphere in which the scattering and absorbing constituents were distributed according to Elterman’s atmospheric profile. It was shown that the magnitude of the near-target PSF depends strongly on the near-forward scattering characteristics and optical thickness of the aerosols between the sensor and target. The near-target asymmetry induced in the PSF by non-nadir viewing is minimal for viewing angles less than 20 degrees but rapidly increases with increased viewing angle. Asymmetric contributions of the far-field at high viewing angles may make it difficult to perform accurate measurement of a dark target lying beyond a bright background. Such a scenario would occur, for instance, if a coastal or estuarine scene were being observed at a high viewing angle by a sensor with a ground track lying well inland.

An algorithm was devised which by using the byproducts of the conventional atmospheric correction process to generate the atmospheric PSF, a conventionally processed scene may be corrected for adjacency effect. The correction algorithm is not perfect; it relies on the assumptions that the non-nadir PSF is a scaled version of the nadir PSF, and that the surface beyond the scene is uniform with reflectance equal to the average reflectance of the scene. These assumptions will clearly limit the accuracy of the correction of some scenes, and error in the assumed aerosol phase function may introduce further inaccuracy in the scene correction. But even with these limitations, the correction algorithm has been shown to give reasonable results for a Pine Key, FL, image collected with the NASA Airborne Visible-Infrared Imaging Spectrometer (AVIRIS) from 20km altitude in November 1992.

Finally, a method of approximating the atmospheric PSF without the Monte Carlo calculations was shown. The simple approximation scheme assumed knowledge of the basic PSFs due to aerosol scattering alone, and due to Rayleigh plus Rayleigh-aerosol interactive scattering. The parameters given for the approximation were based on matching Monte Carlo PSF simulations which used the marine aerosol phase function and an atmospheric aerosol distribution based on Elterman's atmospheric profile. Adjusting the PSF approximation for other conditions would require only two or three Monte Carlo PSF simulations under the chosen conditions. Then the parameters of the approximation scheme could be reset to match the new Monte Carlo results.

Error analysis of the correction algorithm is scene dependent, and has proven to be difficult even with a well understood data set. However, even though the error of the correction itself is difficult to quantify, the PSF correction algorithm presented in this paper will point out the relative extent to which pixels of a high contrast scene are degraded by adjacency effect.

The trend toward higher spatial resolution in satellite and high altitude spectrometry implies the intent to make accurate measurements in high contrast regions. Atmospheric adjacency effect, however, will induce large fractional errors in measurements of surface-leaving radiance from dark targets in high contrast settings. Correction for adjacency effect, therefore, will be particularly important for measurement of water-leaving radiance from lakes, rivers, and coastal areas.

A paper titled "Comparison of Measured and Modeled Bottom Reflectance Spectra on the Southeastern Shelf of the Florida Keys" was presented at the SPIE 95 Aerosence conference in Orlando on April 17, 1995 by Lisa Young. Interpretation of remotely sensed data is difficult in coastal regions compared to the open ocean, where optical signals are highly coupled to phytoplankton/ chlorophyll. In estuarine and coastal areas, terrigenous colored dissolved organic matter (CDOM) does not covary with chlorophyll, and if the water column is optically shallow, bottom reflectance confounds interpretation of remote-sensing reflectance (R_{rs}) signals. In order to more accurately model R_{rs} in nearshore environments, bottom reflectance must be adequately characterized.

During research cruises to the Florida Keys region in July, 1994 and March, 1995, reflectance spectra were obtained of various bottom types. R_{rs} measurements obtained during these cruises, as well as, R_{rs} measurements made with the AVIRIS were compared against R_{rs} derived from a hyperspectral model that decouples water column and bottom contributions to the R_{rs} signal.

A paper titled "Estimating primary production at depth from remote sensing" by Lee at el. has been submitted to Applied Optics. Using a common primary production model, and identical photosynthetic parameters, four different methods were used to calculate quanta (Q) and primary production *(P)* at depth for a study of high latitude, North Atlantic waters. The differences among the 4 methods relate to the use of pigment information in the upper water column. Methods 1 and 2 use pigment biomass *(B)* as an input, and a subtropical, empirical relationship between $K_d(\lambda)$ (diffuse attenuation coefficient) and *B* to estimate *Q* at depth. Method 1 uses measured *B*, but Method 2 uses CZCS-derived *B* (subtropical) as inputs. Methods 3 and 4 use phytoplankton absorption spectra ($a_{ph}(\lambda)$) instead of *B* as inputs, with Method 3 using empirically derived $a_{Ph}(\lambda)$ and $K_d(\lambda)$ values, and Method 4 using analytically derived $a_{ph}(\lambda)$ and $a(\lambda)$ (total absorption coefficient) spectra based on remote measurements.

In comparing calculated to measured values of Q(z) and *P(z)*, Method 4 provided the closest results [*P(z)*: $r^2 = 0.95$ (n = 24); and Q(z): $r^2 = 0.92$ (n = 11)]. Method 1 gave the worst results [*P(z)*: $r^2 = 0.56$; and *Q(z)*: $r^2 = 0.81$]. These results indicate that the analytically derived $a_{ph}(\lambda)$ and $a(\lambda)$ *can* be applied to accurately estimate *P(z)* based on ocean-color remote sensing. Curiously, application to subarctic waters of algorithms for *B* and K_d, both of which were empirically developed using subtropical and summer temperate data sets, apparently compensate to some extent for effects due to their implicit dependence on pigment-specific absorption coefficients (a_{ph}*). Clearly using incorrect specific absorption coefficients (subtropical) for both the *B* and K_d algorithm is better than using measured *B* (subarctic) with a subtropically "tuned" K_d algorithm (compare methods 1 & 2). Since $a_{ph}*$ varies temporally and spatially, a method independent of *B* was sought. By rearranging the CZCS algorithm and the primary production expressions, using a_{ph}* instead of *B* as an input in the *P* expression, and relating the CZCS algorithm to a_{ph} instead of *B*, improved results for estimating *P* from remotely sensed data. Most importantly, there is no dependence on an accurate estimation of pigment-specific absorption coefficients for application of the absorption-based methods.

A cruise in fall 1994 to the Arabian Sea confirmed that our chlorophyll a and CDOM algorithm worked well (<40°/0 error) for that season. A second cruise (June-July, 1995) will provide data during the southwest monsoon period to evaluate the changes necessary to the algorithm for more packaged pigments expected during an upwelling season.

PUBLICATIONS

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Lee, Z. P., K.L. Carder, J. Marra, R.G. Steward, M.J. Perry, Estimating primary production at depth from remote sensing, (submitted to Applied Optics).

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